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The GOTHAM survey: chemical evolution of Milky Way globular clusters

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Abstract. Milky Way globular clusters are excellent laboratories for stellar population detailed analysis that can be applied to extragalactic environments with the advent of the 40m-class telescopes like the ELT. The globular cluster population traces the early evolution of the Milky Way which is the field of Galactic archaeology. We present our GlObular clusTer Homogeneous Abundance Measurement (GOTHAM) survey. We derived radial velocities, Teff, log(g), [Fe/H], [Mg/Fe] for red giant stars in one third of all Galactic globular clusters that represent well the Milky Way globular cluster system in terms of metallicity, mass, reddening, and distance. Our method is based on low-resolution spectroscopy and is intrinsically reddening free and efficient even for faint stars. Our [Fe/H] determinations agree with high-resolution results to within 0.08 dex. The GOTHAM survey provides a new metallicity scale for Galactic globular clusters with a significant update of metallicities higher than [Fe/H] > -0.7. We show that the trend of [Mg/Fe] with metallicity is not constant as previously found, because now we have more metal-rich clusters. Moreover, peculiar clusters whose [Mg/Fe] does not match Galactic stars for a given metallicity are discussed. We also measured the CaII triplet index for all stars and we show that the different chemical evolution of Milky Way open clusters, field stars, and globular clusters implies different calibrations of calcium triplet to metallicity.

Keywords. surveys; stars: abundances; stars: Population II; Galaxy: abundances; Galaxy: bulge; Galaxy: halo; globular clusters: general; globular clusters: individual (NGC 104, 2298, 2808, 3201, 4372, 4590, 5634, 5694, 5824, 5897, 5904, 5927, 5946, 6121, 6171, 6254, 6284, 6316, 6356, 6355, 6352, 6366, 6401, 6397, 6426, 6440, 6441, 6453, 6528, 6539, 6553, 6558, 6569, 6656, 6749, 6752, 6838, 6864, 7006, 7078, Pal 6, 10, 11, 14, Rup 106, BH 176, Lynga 7, HP 1, Djorg 2, IC 1276, Terzan 8)

1. The GOTHAM survey

Globular clusters are useful tools to study the early evolution of our Galaxy. The atmosphere of their stars retain the chemical information of their formation environment. The chemical evolution of the first few billion years of the Milky Way can be described by red giant stars of its globular clusters. From the observational point of view this is only possible if spectroscopic studies are carried out in a homogeneous way for a representative sample of the Galaxy. Detailed chemical abundances are usually available for bright and isolated stars which is the case of inner halo globular clusters. Fainter stars in distant clusters in the outer halo and highly reddened clusters in the bulge and disc are poorly studied (see Saviane *et al.* 2012b for the status of homogeneous metallicities of Galactic globular clusters). The bulge contains many metal-rich globular clusters and the outer halo contains many accreted globular clusters and should be more studied with the goal of reaching a large sample of Galactic globular clusters with homogeneous abundances.

The GOTHAM survey started without this name at the beginning of the twenty-first century (a review of the survey design can be found at Vasquez *et al.* in prep.). The initial goal was to derive metallicities of Milky Way globular clusters using a same observational setup and analysis to increase the number of clusters with homogeneous metallicity. In addition, the results would be used to select candidates of hosting star-to-star [Fe/H] spread for follow-up (e.g. M 22 as shown by Da Costa *et al.* 2009). The sample selection was designed to study mostly distant and highly reddened globular clusters, which were poorly studied or not studied at all, covering bulge, halo, and disc clusters in the Milky Way. Our sample represents well the Milky Way globular cluster system (see Dias *et al.* 2016a for a detailed analysis of the sample). Low-resolution spectroscopy requires less exposure time than high-resolution spectroscopy which is a big advantage for the large number of faint targets we selected. We observed more than 800 red giant stars in more than 50 globular clusters. Two wavelength regions were chosen, one around the CaII triplet at about 850nm, that is a popular metallicity indicator and useful for radial velocity determination (see Saviane *et al.* 2012a for technical details). The other region is around the MgI triplet at about 520nm from which we derive $T_{\rm eff}$, $\log(g)$, [Fe/H], and [Mg/Fe] (see Dias *et al.* 2015 for technical details).

2. [Mg/Fe] via spectral synthesis: searching for peculiar clusters

We describe here one of the projects we are currently developing within the survey team. For the other projects listed in the abstract we point to the aforementioned references. Dias *et al.* (2016a) showed the distribution of [Mg/Fe] and [α/Fe] versus [Fe/H] for 51 globular clusters based on full spectrum fitting technique described in Dias *et al.* (2015). Their results revealed that [Mg/Fe] distribution for globular clusters follows that of field stars, in contrast to previous findings based on homogeneous and heterogeneous data. We increased the number of clusters more metal-rich than [Fe/H] $>$ -0.7 with [Mg/Fe] known and showed that [Mg/Fe] decreases for metal-rich clusters, but [α/Fe] remains constant (Dias *et al.* 2016a). Moreover no distinction is revealed between accreted clusters (e.g. Rup 106 with known solar [α/Fe], see Villanova *et al.* 2013) and typical Galactic globular clusters. This is not surprising because the method described in Dias *et al.* (2015) was optimised for $T_{\rm eff}$, $\log(g)$, [Fe/H], and abundances of [Mg/Fe] and [α/Fe] were also delivered but as a first approximation. Full spectrum fitting techniques depend on how sensitive the spectral region is to the variation of each parameter (Dias *et al.* 2017 submitted). MgI triplet lines are very strong and sensitive to [Mg/Fe] and [α/Fe], therefore suitable for full spectrum fitting. The limitation is in the parameter space: [Fe/H] values range from -3.0 to +0.5 dex while [α/Fe] ranges from 0.0 to 0.4 dex, which means it is easy to derive metallicity using full spectrum fitting, but the small variations of [α/Fe] are more difficult.

We started a more detailed analysis of the α-element abundances using spectral synthesis with the code PFANT†, described in Barbuy *et al.* (2003) and Coelho *et al.* (2005),

† https://github.com/trevisanj/pfant

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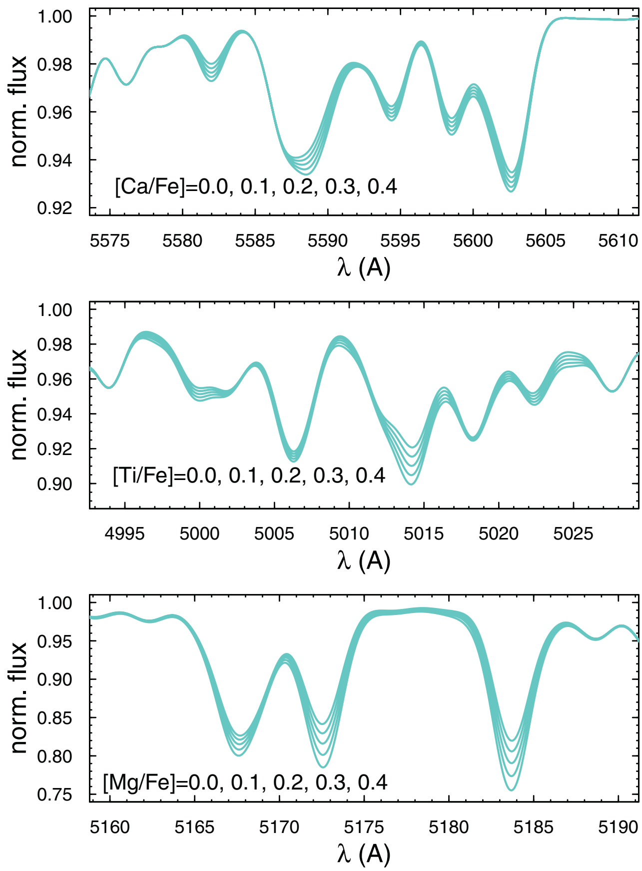

Figure 1. Synthetic spectra using atmospheric parameters of star NGC3201_18: $T_{\rm eff}$ = 5121 K, log(g) = 2.58, [Fe/H] = -1.60. Upper, middle, and lower panel show the effect of a variation on [Ca/Fe], [Ti/Fe], and [Mg/Fe], respectively.

for example. From our previous analysis we already have the radial velocities to put the observed spectrum at rest frame, and the atmospheric parameters to be fixed during the spectral synthesis for each star. The first step was to vary the abundances of all α elements and check the effect on the visible spectral range around MgI triplet. We show in Fig. 1 that Ca and Ti have variations of the order of 1% in flux in very few weak features, while Mg has flux variation of the order of 10% in much stronger features for a change in abundance of 0.4 dex in each element. In conclusion, it is only possible to derive [Mg/Fe] abundance for our dataset. For other α-element abundances higher resolution (or possibly extremely high S/N and low-resolution) spectra is required.

We discuss the preliminary results of our proof-of-concept analysis for two clusters with similar metallicity of [Fe/H] ∼-1.5, NGC 3201 and Rup 106. Figure 2 shows a MgI line of one star per cluster and the synthetic spectra varying [Mg/Fe] from 0.0 to 0.4 dex. For NGC3201_8 we find [Mg/Fe]≈0.4, which is typical of Milky Way stars of similar metallicity, and in agreement with the high-resolution spectroscopic average [Mg/Fe]=0.38±0.03 (Muñoz *et al.* 2013). Rup106_11 presents [Mg/Fe]≈0.0 in agreement with dwarf galaxy stars of similar metallicity, and in agreement with the high-resolution spectroscopic average [Mg/Fe]=-0.02±0.01 (Villanova et al. 2013). Other stars were analysed for these clusters and no spread in [Mg/Fe] was found, in agreement with the references cited

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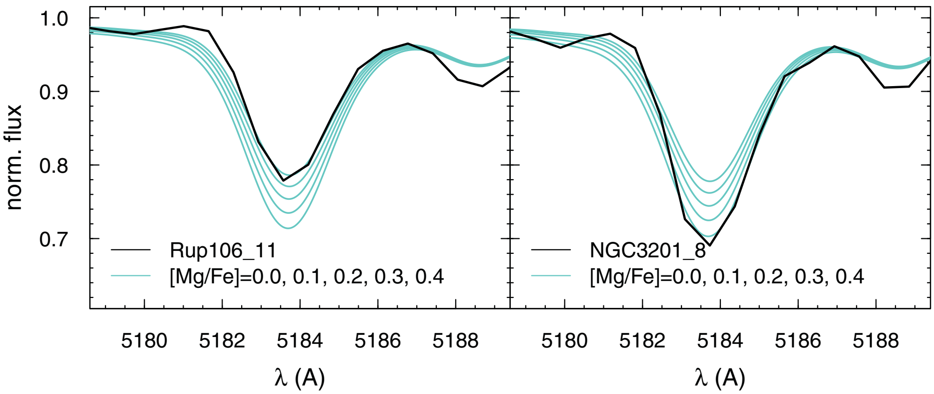

Figure 2. MgI line of one star from NGC 3201 and another from Rup 106, both clusters with metallicity of [Fe/H]$\sim$-1.5 and different α-element enhancement. The star Rup106_11 has [Mg/Fe]$\approx$0.0 and NGC3201_8 has [Mg/Fe]$\approx$0.4. The atmospheric parameter of Rup106_11 are: $T_{\rm eff}$ = 4838 K, log(g) = 1.88, [Fe/H] = -1.52, and NGC3201_8 has $T_{\rm eff}$ = 4706 K, log(g) = 1.62, [Fe/H] = -1.50.

above. These MgI lines are very strong and should be used carefully. Further efforts to calibrate the MgI lines, as it is done for the CaII triplet lines, are under way. We intend to use this approach to identify other clusters with different [Mg/Fe] from the Milky Way pattern, for future follow-up.

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Discussion

RECIO-BLANCO: Globular clusters present a star-to-star [Mg/Fe] variation and you showed only one star per cluster. What about the other stars?

DIAS: Other stars in Rup 106 and NGC 3201 have similar [Mg/Fe] based on our data. This result agrees with Villanova *et al.* (2013) and Muñoz *et al.* (2013) who analysed high-resolution spectra for Rup 106 and NGC 3201. Note also that the [Mg/Fe] spread only occurs in rare clusters with extreme populations as discussed by e.g. Carretta *et al.*(2009) and Da Costa *et al.*(2013).

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